भारतीय मानक
Indian Standard

IS 516 (Part 2/Sec 3) : 2022

दृढ़ीकृत कंक्रीट — परीक्षण पद्धतियाँ

भाग 2 सामर्थ्य बल के अतिरिक्त दृढ़ीकृत कंक्रीट के अन्य गुण

अनुभाग 3 ऑक्सीजन भेधता सूचकांक

(पहला पुनरीक्षण)

Hardened Concrete — Methods of Test

Part 2 Properties of Hardened Concrete other than Strength

Section 3 Oxygen Permeability Index

(First Revision)

ICS 91.100.30

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुरशाह ज़फर मार्ग, नई दिल्ली – 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI-110002
www.bis.gov.in www.standardsbis.in

January 2022 **Price Group 6**

Cement and Concrete Sectional Committee, CED 02

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards after the draft finalized by the Cement and Concrete Sectional Committee had been approved by the Civil Engineering Division Council.

Testing plays an important role in determining the durability of concrete. Systematic testing of the raw materials, the fresh concrete and the hardened concrete is an inseparable part of any quality control programme for concrete. Which helps to achieve a higher efficiency of the materials used and greater assurance of the performance of the concrete in regard to both strength and durability. The test methods used should be simple, direct and convenient to apply. This standard has been prepared with this objective in view and provides a guide to the determination of oxygen permeability index of concrete.

This standard was first published in 1959. In this revision, it was decided to review and update the various existing test methods of concrete taking into consideration the latest international practices and developments in this field in the country, and also to introduce certain new test methods, wherever required. In the process, the various existing test methods covered in IS 516 : 1959 'Methods of tests for strength of concrete' have been revised. The revision of the standard is being brought out taking into consideration primarily the corresponding ISO standards while also examining the other best practices world over and in the country. In addition, test methods for determination of additional properties have been included in areas such as permeability, initial surface absorption, corrosion of reinforcement, carbonation of concrete (field test) and, creep of concrete. Also, for better understanding and implementation, some of the other test methods which were spread over in number of other Indian Standards have been brought together under the fold of IS 516 as its various parts, such as the splitting tensile strength, ultrasonic pulse velocity test, rebound hammer test, bond in reinforced concrete, and determination of water soluble and acid soluble chlorides. This is with a view to making the standard complete in all respects, and rendering it a comprehensive source of provisions for testing of concrete and reference in other Indian Standards.

In this revision, IS 516 has been split into 12 parts. The other parts in the series are:

Part 1 Determination of strength of hardened concrete

Part 3 Making, curing and determining compressive strength of accelerated cured concrete test specimens

Part 4 Sampling, preparing and testing of concrete cores

Part 5 Non-destructive testing of hardened concrete

Part 6 Determination of drying shrinkage and moisture movement of concrete samples

Part 7 Determination of creep of concrete cylinders in compression

Part 8 Determination of modulus of elasticity in compression

Part 9 Determination of wear resistance

Part 10 Determination of bond in reinforced concrete

Part 11 Determination of Portland cement content of hardened hydraulic cement concrete

Part 12 Determination of water soluble and acid soluble chlorides in hardened mortar and concrete

Part 2 of the standard is further subdivided into 3 sections. The other sections being Sec 1 on Density of Hardened Concrete and Depth of Water Penetration Under Pressure and Sec 2 on Initial surface absorption. This standard (Part 2/Sec 3) covers the testing procedure for determination of oxygen permeability index of concrete having maximum nominal size of the aggregate not more than 20 mm. IS 516 shall be superseded after the publication of all the parts of the standard.

In the preparation of this standard, assistance was derived from the following publications:

RILEM TC-230 Performance-Based Specifications and Control of Concrete Durability (*State-of-the-art-report*), Springer, 2016

SANS 3001-CO3-2:2015 Civil Engineering Test Methods Part CO3-2: Concrete Durability Index Testing – Oxygen Permeability Test

Durability Index Testing Procedure Manual, University of Cape Town, South Africa

The composition of the Committee responsible for the formulation of this standard is given in Annex B.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that specified value in this standard.

Indian Standard

HARDENED CONCRETE — METHODS OF TEST

PART 2 PROPERTIES OF HARDENED CONCRETE OTHER THAN STRENGTH

Section 3 Oxygen Permeability Index

(First Revision)

1 SCOPE

This standard (Part 2/Sec 3) covers the test for the determination of oxygen permeability index of cement concrete having maximum nominal size of the aggregate not more than 20 mm.

2 REFERENCES

The following standards contain provisions, which through reference in this text constitute provisions of this standard. At the time of publication, the editions indicated were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS No.	*Title*
516 (Part 4) : 2018	Hardened concrete — Methods of test: Part 4 Sampling, preparing and testing of concrete cores
1199 (Part 5) : 2018	Fresh concrete — Methods of sampling, testing and analysis: Part 5 Making and curing of test specimens

3 DETERMINATION OF OXYGEN PERMEABILITY INDEX

3.1 Principle

This test determines the gas permeability of concrete through the use of oxygen gas, where oxygen permeability index is defined as the negative log of the coefficient of permeability. It consists of measuring the pressure decay of oxygen passed through a 30 mm oven-dried thick slice (representing the cover concrete) of a (typically) 70 mm diameter concrete core placed in a falling head permeability apparatus.

3.2 Apparatus

3.2.1 *Water-cooled Diamond Tipped Core Barrel,* having a nominal inner diameter of 70 mm, attached to a suitable coring drill.

3.2.2 *Holding Device*, in which cubes can be clamped firmly and securely to ensure they remain in position while coring takes place.

3.2.3 *Water-cooled Moveable Bed Diamond Saw*, for slicing concrete.

3.2.4 *Facing Machine* (Optional), in case the saw cuts do not produce perfectly flat surfaces.

3.2.5 *Oven,* in which temperature can be maintained at 50 ± 2 ºC.

3.2.6 *Permeability Test Arrangement,* as shown in Fig. 1. The schematic of the apparatus is shown in Fig. 2. The permeability cell shall have a volume of 5 litre ± 5 percent. The permeability cell shall be kept in room with a controlled temperature of 27 ± 2 ºC.

3.2.7 *Compressible Rubber Collars*, having hardness 39 Shore A, for each cell as shown in Fig. 3.

3.2.8 *Gauges or Pressure Transducers*, having least count of 0.5 kPa.

3.2.9 *Regulator*, capable of regulating pressure up to 120 kPa of standard grade 99.8 percent oxygen supply.

3.2.10 *Vernier Caliper*, having least count of 0.02 mm.

3.2.11 *Desiccator*, with the relative humidity controlled at a maximum of 60 percent, if relative humidity in the laboratory is more than 60 percent.

3.3 Test Specimens

A minimum of four test specimens shall be required. Each specimen shall consist of a 70 ± 2 mm diameter concrete disc with a thickness of 30 ± 2 mm cored and cut as per **3.4.1**, or alternatively, 75 ± 2 mm diameter concrete discs of thickness of 30 ± 2 mm obtained

by sawing from a 75 mm × 150 mm cast cylindrical specimen, as per **3.4.2**.

3.4 Sample Preparation

3.4.1 *Preparation of Specimens from Cubes in the Laboratory*

Concrete cubes shall be cast and cured as per IS 1199 (Part 5), and with minimum dimensions of 100 mm. Coring shall be performed at 28 ± 3 days after casting as per IS 516 (Part 4), unless otherwise required by project specifications. The first 5 mm from the face of the core shall be removed. Disc specimens having thickness as 30 ± 2 mm and diameter as 70 ± 2 mm shall be cut from the core. The specimen shall be discarded, if it is damaged during the coring and cutting process.

3.4.2 *Preparation of Specimens from Cast Cylinders in the Laboratory*

In the case of preparation of specimens from cast cylinders in the laboratory, the standard procedure for casting and curing [up to 28 ± 3 days after casting as per IS 1199 (Part 5)] should be followed to obtain cylinders of 75 mm × 150 mm. The first 5 mm from the cast surface shall be removed. Disc specimens of thickness (30 ± 2 mm) shall be cut from the cylindrical specimen.

3.4.3 *Preparation of Specimens from Site Elements*

If it is necessary to establish the oxygen permeability value in the structural concrete, adequate number of cores shall be extracted directly from the structure or site elements itself, as prescribed by the project specification. Disc specimens shall be prepared as per **3.4.1** or **3.4.2**.

NOTE — Coring should be performed in the direction perpendicular to the direction of casting to avoid the influence of bleed channels on the permeability measurements.

3.5 Conditioning

3.5.1 Specimen conditioning shall comprise of drying of specimen in an oven at 50 ± 2 °C for 7 days ± 4 h.

3.5.2 An alternative methodology for drying can be adopted with different temperature and duration of drying based on sufficient number of trials. This alternative method should result in same efficacy, that is, the same level of moisture content removed, when dried as per **3.5.1**. The maximum temperature adopted for alternative methodology shall not be more than 75 °C.

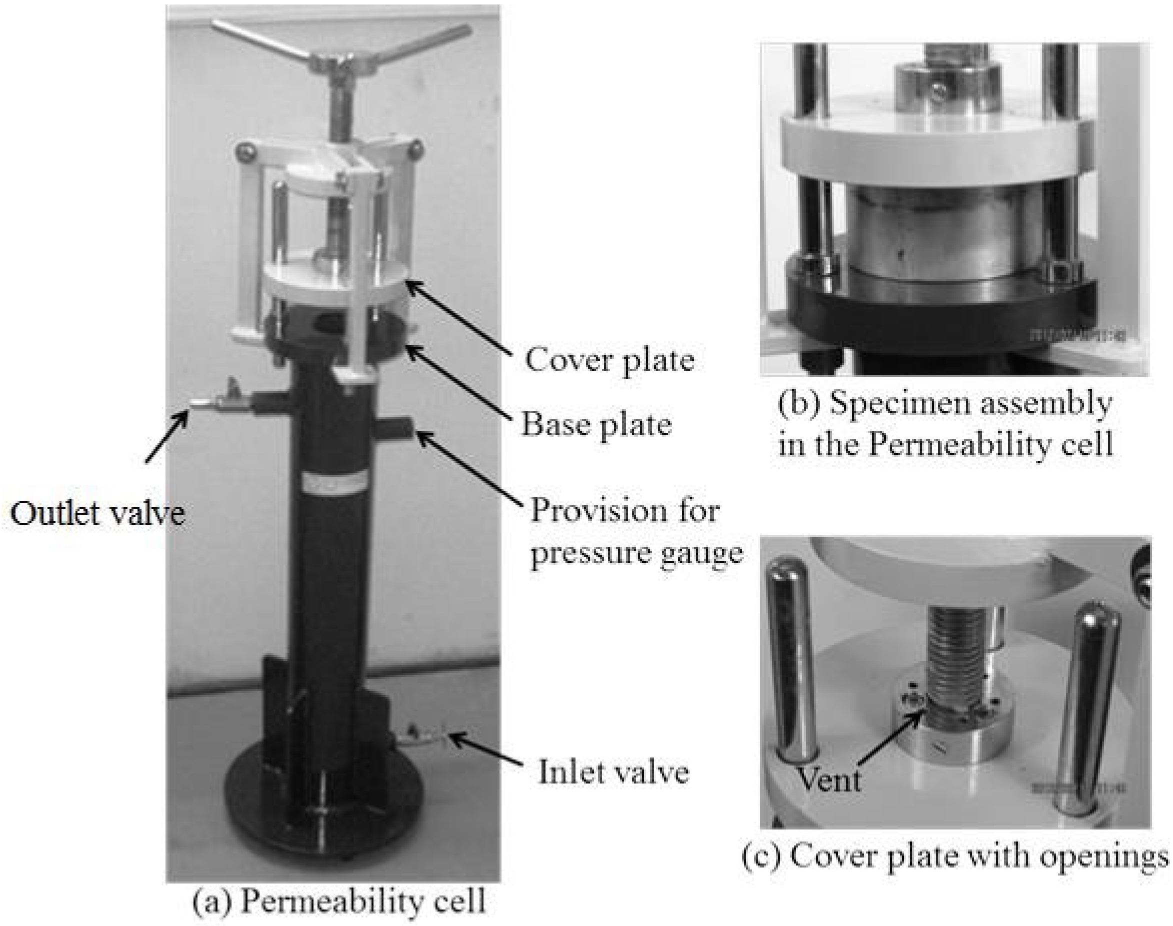
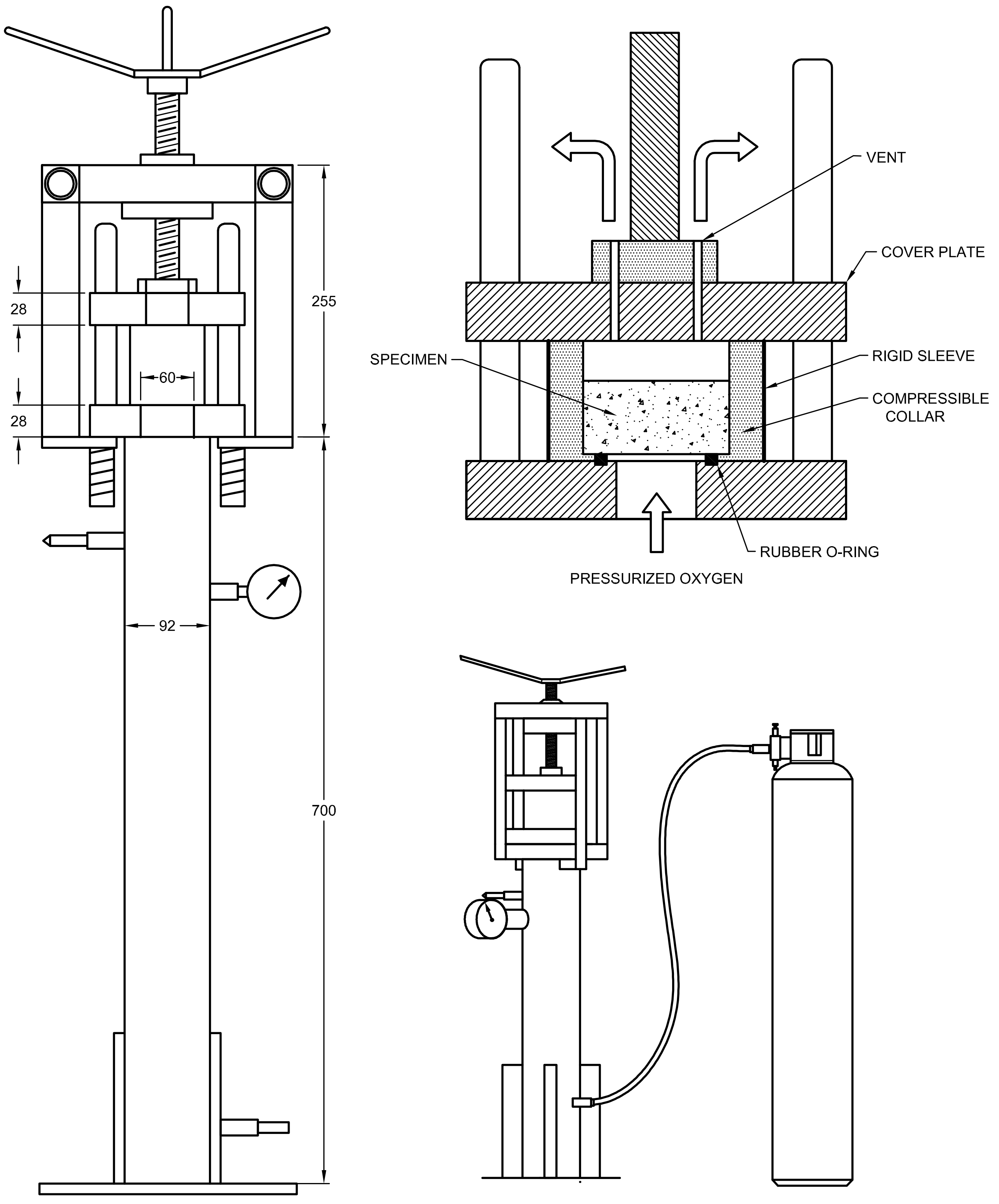
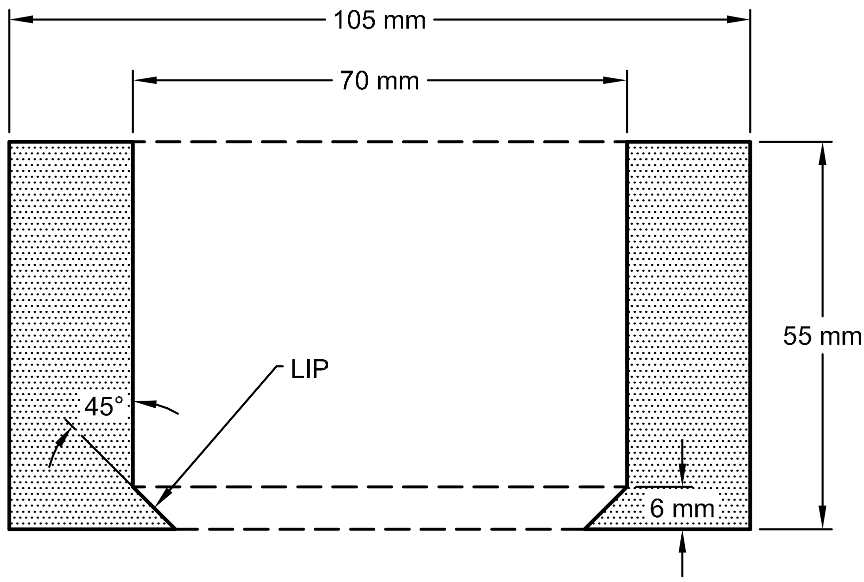


FIG. 1 OXYGEN PERMEABILITY INDEX APPARATUS AND THE CELL ASSEMBLY



All dimensions in millimetres

FIG. 2 SCHEMATIC OF THE OXYGEN PERMEABILITY SET-UP



NOTE — This is for 70 mm specimens prepared from cores; suitable modifications should be made for 75 mm diameter sliced specimens

FIG. 3 COMPRESSIBLE COLLAR

3.6 Procedure

After the completion of the conditioning period, the specimens shall be cooled to 27 ± 2 °C, either in a desiccator or in a room with ambient conditions controlled at a temperature of 27 ± 2 °C and relative humidity less than 60 percent. The diameter and thickness of each specimen shall be taken as an average of readings obtained at four points, equally spaced around the perimeter of the specimen, to the nearest 0.02 mm. The specimen shall be placed in the compressible collar with the test face flushed to the lip of the collar, which shall then be inserted into the rigid sleeve. The inner diameter of the rigid sleeve, which can be made from hard plastic or from steel, shall be 105 mm in case of specimens prepared from 70 mm cores, or 110 mm in case of specimens prepared from cast cylinders of 75 mm diameter. Materials, such as foam tape and rubber may be used to ensure tight fitting of the specimen in the compressible collar. The specimen assembly shall be placed in the test chamber with the test face of the specimen covering the hole as shown in Fig. 2. The other end of the specimen assembly shall be closed with the cover plate. The cover plate shall be tightened properly using a spanner.

Before the start of the test, the permeability cell shall be purged with oxygen so as to expel all the other gases present in the chamber. The purging shall be done by opening both the inlet and outlet valves of the permeability cell for at least 5 s. The outlet valve shall then be closed to increase the pressure in the chamber. The inlet and outlet valves shall be operated, such as to obtain an initial pressure of 100 ± 5 kPa. This time shall be recorded as the initial time, t0, to the nearest minute and initial exact pressure, *P0*, to the nearest 0.5 kPa. The test shall be continued for 6 h ± 15 min or until the pressure drops to 50 ± 2.5 kPa, whichever occurs first. A minimum of eight readings of instantaneous pressure, *Pt* at time = *t* shall be taken during the test.

NOTES

1 If the pressure drops at a rate more than 5 kPa per minute, it shows leakages present in the arrangement. These leakages shall be rectified before commencing the test.

2 The permeability cell shall be checked for air tightness on a regular basis using an impermeable test specimen. The cell shall be accepted if the drop in pressure in such a test is not more than zero kPa at an initial applied pressure of 100 kPa for a period of 24 h.

3.7 Calculation

3.7.1 A linear regression analysis shall be performed between $log_e\left(\frac{P_t}{P_0}\right)$ and t with the line passing through the origin (0, 0). The acceptable regression coefficient shall be greater than 0.99. Test shall be repeated if the regression coefficient is less than 0.99. The specimen shall be discarded in the event of repeated failures in achieving a coefficient of correlation greater than 0.99. The slope of the linear regression line passing through the origin (0, 0) may be calculated from the equation.

$$z = \frac{\sum\left[\log_e\left(\frac{P_0}{P_t}\right)\right]^2}{\sum\left[t.\log_e\left(\frac{P_0}{P_t}\right)\right]}$$

where

z = slope of the line from the linear regression analysis;

P_0 = initial pressure; and

P_t = pressure at time t.

The r^2 value may be calculated from the equation:

$$r = 1 - \frac{\sum\left(t_i - t_{p,i}\right)^2}{\sum t_i^2 - \frac{\left(\sum t_{p,i}\right)^2}{n}}$$

where

t_i = time at any given pressure reading;

$t_{p,i}$ = predicted time at the same pressure reading, based on the linear regression; and

n = number of data points being considered.

3.7.2 Darcy's coefficient of permeability, k is given by:

$$k = \frac{mVgdz}{RA\theta}$$

where

k = Darcy's coefficient of permeability, in m/s;

m = molecular mass of oxygen, in kg/mol (= 0.032 kg/mol);

V = volume of the pressurised oxygen in the permeability cell, in m^3 (measured to the nearest 0.00001 m^3). The volume may be calculated using the measured dimensions or may be directly measured by the volume of water contained at 27 ± 2 °C;

g = acceleration due to gravity (= 9.81 m/s^2);

d = thickness of the specimen, in m;

z = slope of the best fit line, in reciprocal second (s^{-1});

R = gas constant, in $JK^{-1}mol^{-1}$ (= 8.313 $JK^{-1}mol^{-1}$);

θ = absolute temperature, in K; and

A = cross-sectional area of the test specimen, in m^2.

The Darcy's coefficient of permeability shall be calculated for each test specimen. The oxygen permeability index, OPI of the concrete shall be calculated as:

$$OPI = -\log_{10}\frac{(k_1 + k_2 + k_3 + ... + k_n)}{\text{n}}$$

The suggested qualitative classification of concrete based on the oxygen permeability index is given in the Annex A for informative purpose.

3.8 Report

3.8.1 The following information shall be included in the report on each test specimen:

a) Darcy's coefficient of permeability, k for each specimen correct to three decimal places;
b) The oxygen permeability index, *OPI* correct to two decimal places;
c) Identification number of specimens; and
d) Description of specimen (state if there are any visible cracks, honeycombing defects or visible bleed paths present).

3.8.2 The following, if known, shall also be reported:

a) Source of the specimen;
b) Location of specimen within cube (or cylinder), core or member;
c) Identification mark of each specimen;
d) Type of concrete, including binder type, water/cement ratio and other relevant data supplied with the specimen;
e) Curing history;
f) Unusual specimen preparation for example, removal of surface treatment;
g) Unusual features such as cracks, voids, excessively chipped edges, etc; and
h) Age of concrete at the time of testing.

ANNEX A

(*Informative*)

(*Clause* 3.7.2)

RELEVANCE OF THE OXYGEN PERMEABILITY INDEX TEST

A-1 Permeability is a measure of the capacity of concrete to transfer fluids by permeation where the driving force is the pressure difference. The permeability of concrete is dependent on different factors, such as microstructure of concrete, moisture condition of the specimen and the features of the permeating agent. Gas permeability measurements are important in the case of concrete durability as they are directly related to carbonation as well as propagation of corrosion. The oxygen permeability index test can be used to detect differences in water-cement ratio, binder type, and curing condition of different concretes. Further, the results from oxygen permeability index test are well correlated with other existing test methods such as torrent air permeability test and carbonation depth in accelerated carbonation measurements.

A-2 Following are the merits and demerits of oxygen permeability index test:

A-2.1 Merits

a) Good correlation with accelerated carbonation test.
b) The pore structure doesn't get modified during test as oxygen doesn't react with concrete.
c) Assesses the overall micro and macrostructure of the outer surface of cast concrete, thus useful to assess the state of compaction, presence of bleed voids and channels, and the degree of interconnectedness of the pore structure.

A-2.2 Demerits

a) Sensitive to macro voids and cracks.
b) Sensitive to the specimen preparation.
c) Difficult to conduct the tests for concrete having dense micro structure such as high performance concrete.

A-3 CLASSIFICATION CRITERIA

The classification criteria for concrete quality based on the oxygen permeability index is given in Table 1.

Table 1 Concrete Quality Classification Based on Oxygen Permeability Index

(*Clause* A-3)

Sl No.	Oxygen Permeability Index	Concrete Quality
(1)	(2)	(3)
i)	Above 10.0	Very good
ii)	9.5 to 10.0	Good
iii)	Below 9.5	Poor

ANNEX B

(*Foreword*)

COMMITTEE COMPOSITION

Cement and Concrete Sectional Committee, CED 02

Organization	*Representative(s)*
In Personal Capacity (*Grace Villa, Kadamankulam PO, Thiruvalla 689583, Kerala*)	Shri Jose Kurian (***Chairman***)
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In Personal Capacity [*B-806, Oberoi Exquisite Oberoi Garden City, Goregaon* (*East*)*, Mumbai 400063*]	Shri A. K. Jain
In Personal Capacity (*36, Old Sneh Nagar, Wardha Road, Nagpur 440015*)	Shri L. K. Jain

Organization	*Representative(s)*
In Personal Capacity (*EA-92, Maya Enclave Hari Nagar, New Delhi 110064*)	Shri R. C. Wason
BIS Directorate General	Shri Sanjay Pant, Scientist 'F' and Head (Civil Engineering) [Representing Director General (*Ex-officio*)]

Member Secretaries

Shri Arun Kumar S.
Scientist 'E' (Civil Engineering), BIS

and

Shrimati Divya S.
Scientist 'C' (Civil Engineering), BIS

Concrete Subcommittee, CED 2 : 2

Organization	*Representative(s)*
In Personal Capacity (*Grace Villa, Kadamankulam P.O., Thiruvalla* 689583)	Shri Jose Kurian (***Convener***)
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Ready Mixed Concrete Manufacturers' Association, Mumbai	Shri Vijaykumar R. Kulkarni Shri Srirang Sondur (*Alternate*)
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Ultra Tech Cement Ltd, Mumbai	Dr V. Ramachandra Dr A. K. Singh (*Alternate*)
Water Resource Department, Govt of Madhya Pradesh, Mumbai	Shri S. K. Khare Shri B. P. Gupta (*Alternate*)
In personal capacity (*452 Sector 14, Sonipat, Haryana*)	Shri R. K. Jain
In personal capacity (*36, Old Sneh Nagar, Wardha Road, Nagpur*)	Shri L. K. Jain
In personal capacity [*B-803, Oberoi Exquisite, Oberoi Garden City, Goregaon (East), Mumbai]*	Shri A. K. Jain
In personal capacity (*EA-92, Maya Enclave, Hari Nagar, New Delhi*)	Shri R. C. Wason
In personal capacity (*M1 F1 VGN Minerva Apartments, Guruswamy Road, Nolambur*, *Chennai*)	Dr C. Rajkumar

Panel for Revision of Indian Standards on Test Methods for Concrete, CED 2 : 2/P7

Organization	*Representative(s)*
In Personal Capacity (*EA-92, Maya Enclave, Hari Nagar, New Delhi* 110064)	Shri R. C. Wason (***Convener***)
ACC Limited, Mumbai	Shri Avijit Chaubey Shri Prahalad Majumdar (*Alternate*)
AIMIL Ltd, New Delhi	Dr V. M. Sharma
Bureau Veritas India Limited, Bengaluru	Representative
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